SOME NOTES ON THE FRANKFORT INTERNATIONAL ELECTRICAL EXHIBITION.[1]

VI.

The Frankfort Motor and the Lauffen Dynamo.

IN all the motors described in Part V. the magnetism of the stationary iron ring is being rapidly reversed, while that of the moving interior varies at a rate which is equal to only the difference between the speeds of the rotatory magnetic field and the rotating central portion of the motor. This difference is always comparatively small in a well-designed multiphase motor, even when loaded, and becomes practically nought for light loads. Hence we may regard a multiphase motor as roughly one in which the magnetism of the rotating iron interior remains unchanged relatively to the iron itself, while that of the stationary iron ring varies rapidly.

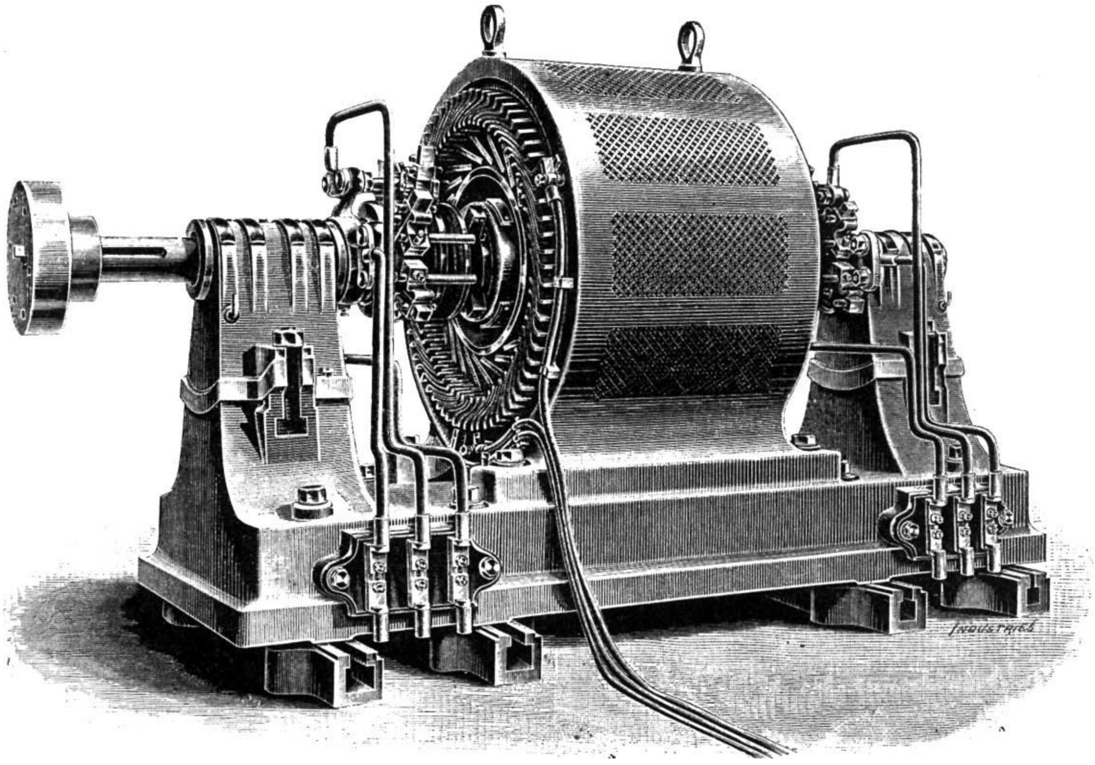

FIG. 32.—The Frankfort 100 horse-power rotatory current motor.

Now whenever the magnetism of iron is being rapidly reversed, there is loss of power; the magnitude of the loss, for a given rate of reversal and quality of iron, depending on the intensity of the magnetization and the mass of the iron acted on. And, as the length of the lines of force in the outer stationary iron ring of the multiphase motor is necessarily longer than in the interior rotating portion, Mr. Dobrowolski concluded that less power would be wasted if he inverted the functions of the stationary and rotating parts, sending the multiphase alternate currents round the interior rotating laminated iron drum, and attaching the short-circuited conductors, in which currents are induced by the rotating magnetic field, to the *inside* of the stationary laminated iron ring, so as to form a kind of short-circuited Siemens armature turned inside out.

The preceding conclusion is undoubtedly correct if it be certain that *the smaller density of the lines of force in the stationary ring do not more than compensate for the increased length of their path*, a point to which we venture to think Mr. Dobrowolski has not given sufficient attention when coming to this decision to turn the multiphase motor inside out.

However, be that as it may, Fig. 32 shows the multiphase motor of 100 horse-power nominal, which the considerations described in this and the previous article led Mr. Dobrowolski to construct for being worked at Frankfort by a portion of the power generated at Lauffen 109 miles away.

To lead the currents coming along the mains to the rotating interior of the motor, three rubbing contacts must be employed; indeed, six contacts become necessary if we desire to be able to couple up the coils on the motor in open or closed circuits (Figs. 20 and 24, pp. 56 and 57)—an arrangement provided for in the Frankfort motor (Fig. 32). The great simplicity of the original Ferraris' motor is thus abandoned, but, although this would be disadvantageous in the case of small motors, where simplicity and freedom from sparking are all-important, the change is not so serious in a large motor, like that shown in Fig. 32, since high efficiency, and therefore small waste of power, combined with relatively small first cost, are the main things to be aimed at in large motors.

Another reason why the application of rubbing contacts to a large rotatory-field motor is less objectionable than might at first sight appear arises from the fact that, even if the motor were constructed in one of the original forms shown in the preceding article, it would be necessary to employ rubbing contacts for a totally different reason, viz. to introduce resistance, at the moment of starting the motor, into the circuits which carry the currents induced by the rotating magnetic field. Whereas, if these currents be induced in conductors attached to the stationary ring, such a resistance can be introduced without extra rubbing contacts; and it is for the purpose of introducing this resistance into these stationary circuits that the three wires, trailing on the ground in Fig. 32, are seen attached to the conductors attached inside the stationary part of the motor.

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[1] Concluded from p. 60.

The necessity, at starting the motor, for increasing the resistance of the conductors carrying the induced currents will appear from the following consideration. When the motor (Fig. 32) is running at full speed under a light load, the interior part rotates at such a rate—relatively to the frequency of alternation of the currents in the main wires—that the magnetic field is practically stationary, just as it is in an ordinary direct current motor. But at the start, the interior laminated iron drum is only moving slowly, while the currents flowing in the conductors attached to it are alternating rapidly, hence the magnetic field is rotating rapidly, and powerful currents are induced in the stationary conductors, so powerful, in fact, as to produce a magnetic field which seriously distorts that produced by the main alternating currents. In fact, there is the same antagonism of magnetic fields that occurs with a direct current motor, if the armature field be very powerful in comparison with that of the field magnet, and if the lead of the brushes be adjusted so as to cause the fields to oppose one another; and it is to avoid this result that M. Dobrowolski introduces a liquid resistance into the circuits of the stationary conductors of his large motors while the motor is getting up speed.

We have hitherto spoken of the conductors on the rotating part as being wound on the outside of a laminated iron drum, and those on the stationary part as being wound on the inner surface of a laminated iron ring; but, as a matter of fact, in the large Frankfort motor both sets are composed of copper rods, insulated in asbestos tubes, and slipped into holes punched out of the iron close to the periphery. This burying of the copper bars to a small depth inside the iron has been adopted because it has been found that the generation of Foucault currents in the thick bars can in this way be more effectively prevented than by following the method usually adopted with bar armatures, which consists in moulding each conductor out of stranded copper wire with the various wires composing the strand partially insulated from one another.

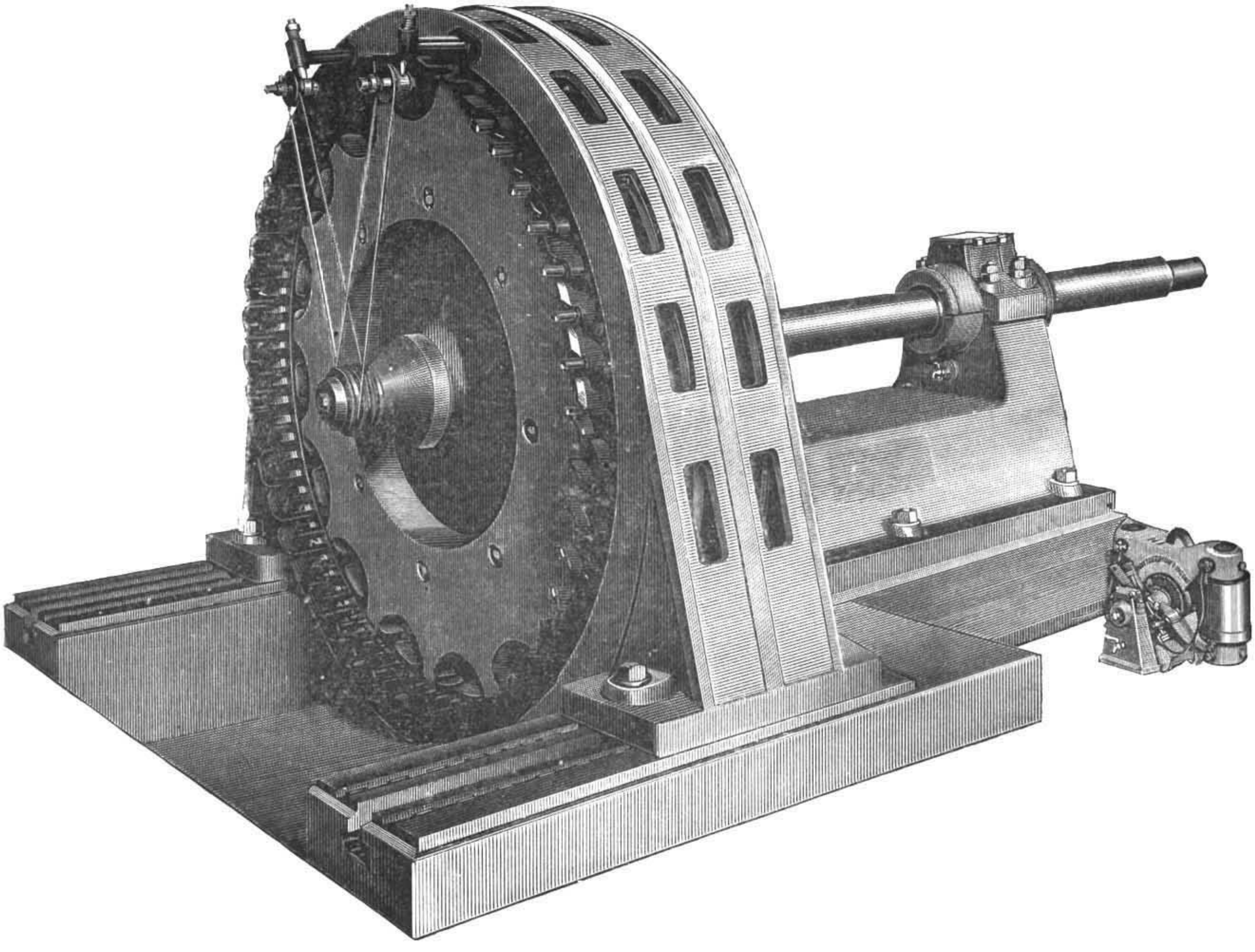

Fig. 33.—The Lauffen three-phase alternate current dynamo and exciter.

No tests have yet been published of the power and efficiency of this machine, but the smoothness with which it ran, pumping up water for the artificial waterfall in the Frankfort Exhibition, and the absence of the roar audible with some alternate current machines, and even of the rhythmical hum noticeable with the best alternate current motors, were very striking.

In the last article it was proved that if three harmonic alternating currents of the same periodic time and maximum amplitude, but differing by 120° in phase, flowed in three wires, A, B, C (Figs. 20, 21, 22), each current was at any moment algebraically equal to the sum of the other two. To test, therefore, whether the currents flowing in the three parallel wires between Lauffen and Frankfort fulfilled this condition, we had merely to find out whether any current was induced in a neighbouring telegraph wire which was sufficiently far away as to be practically at the same distance from each of the Lauffen-Frankfort wires.

Between Frankfort and Hanau the power wires are carried on one side of a broad railway, and for some eight or nine miles the telegraph wires run on the other side; the telegraph wires for the remainder of the distance between Frankfort and Hanau following quite a different route. If one of these telegraph wires were put to earth at Frankfort and at Hanau, and if a telephone were placed in the circuit, a confused chattering of telegraph instruments was always heard in this telephone, due to induction from the telegraph lines on the same posts. But during the hours that power was being transmitted through the wires on the other side of the broad railway a rhythmical hum could be detected superimposed on the confused babel of telegraph signals, proving that the three alternate currents were either not truly sine currents, or that their phase difference was not accurately 120°.

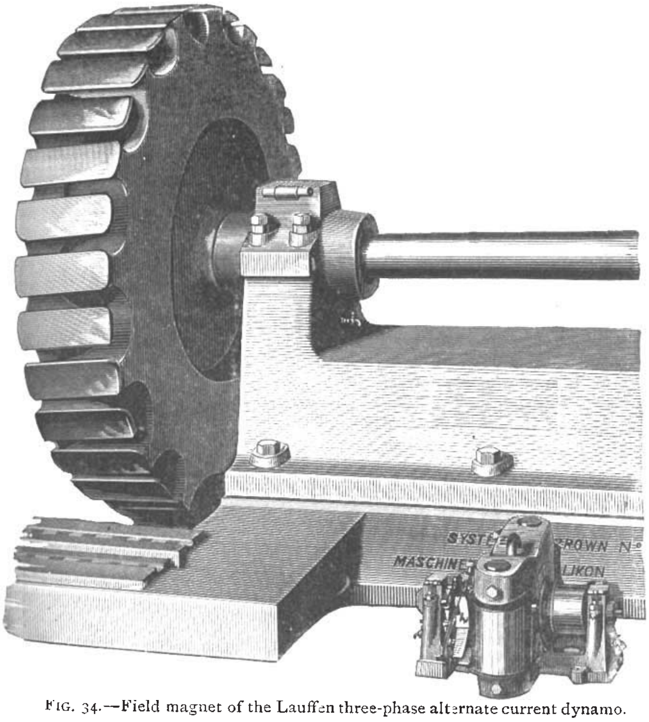

FIG. 34.—Field magnet of the Lauffen three-phase alternate current dynamo.

To generate the three-phase current at Lauffen, the extremely compact dynamo shown in Fig. 33 was designed by Mr. Brown, and constructed at the Oerlikon Works, near Zurich. The armature is wound with three distinct circuits, each arranged to give 1400 amperes at a potential difference of 50 volts, so that the dynamo can develop 300 horse-power. To avoid, as far as possible, rubbing contacts, the armature remains stationary and the field magnet revolves; while by the employment of 32 poles a frequency of 40 complete alternations per second can be obtained in each circuit when the field magnet only makes 150 revolutions per minute.

For examining the interior, the armature, which forms the outside shell of the machine, can be withdrawn sideways, leaving the field magnet in position, as seen in Fig. 34. Each of the 32 flat-looking plates round the circumference of the field-magnet is a magnetic pole, the poles being alternately north and south. This result is attained by constructing the field magnet in the ingenious manner shown in Fig. 35, the coil which carries the direct current to magnetize this field magnet being wound in the circumferential channel seen in section in Fig. 35.

The armature bars, 96 in number, are constructed of copper rods 29 mm. in diameter, insulated in asbestos tubes, and slipped through holes (parallel to the axis of rotation) punched out of the laminated iron ring which composes the armature core; this burying of the conductors to a small depth in the iron being, as already explained in the case of the Dobrowolski motor, for the purpose of avoiding Foucault currents being induced in the thick copper bars.

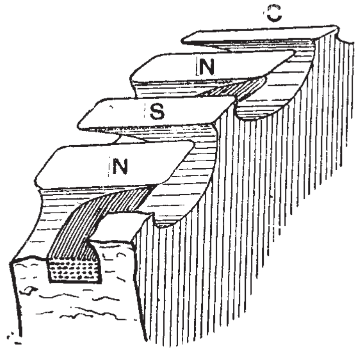

FIG. 35.—Section of the field magnet of the Lauffen dynamo.

A portion of the three separate windings, *a a a a*, *b b b b*, *c c c c*, on the armature is shown in Fig. 36, which represents a bit of the circumferential part laid out flat; the dotted rectangles indicate the poles, and to avoid confusion the armature bars, parallel to the length of the poles, are drawn longer in proportion than they really are.

In order that the electromotive forces induced in all the up and down bars of any one of the windings *a a a a* in Fig. 36 should help one another, the distance between any up and the adjacent down conductor of the same winding must be equal to the distance between two adjacent poles—that is, to 1/32 of the circumference of the armature; and in order that the electromotive force generated by the winding *b b b b* should differ in phase by 120° from the electromotive force generated in the winding *a a a a*, the distance between an up bar of the winding *a a a a* and the following up bar of the winding *b b b b* must be two-thirds of the distance between the centres of two adjacent poles—that is, must be 1/48 of the circumference of the armature. Similarly, an up bar of the winding *c c c c* must be behind the preceding up bar of the winding *c c c c* by 1/48 of the circumference of the armature.

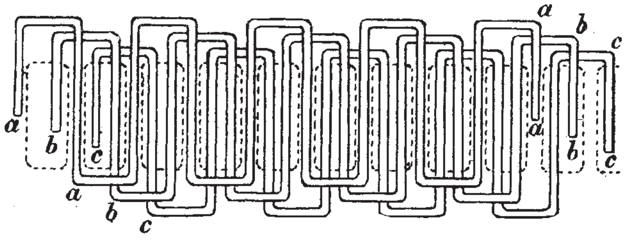

FIG. 36.—Portion of the armature-winding of the Lauffen three-phase alternate current dynamo.

The exciting current is led into the field magnet by the novel employment of the two endless metallic cords seen to the left of Fig. 33, which saves the necessity of using a standard to carry contact brushes, and the smallness of the power spent in exciting the field magnet, compared with the power developed by the machine, is seen from the dwarf-like character of the direct current exciting dynamo in Figs. 33 and 34.[1]

This three-phase alternate current dynamo of Mr. Brown's, on account of the simplicity and solidity of its design, the slow speed of its rotation, and the entire absence of the experimental makeshifts which are supposed to be characteristic of an electrician, but which are in reality evidences of the rapid development of his tools, appeals especially to the mechanical engineer. It is therefore probable that the employment of so well constructed a dynamo at Lauffen, and so smoothly running a motor at Frankfort, will bring home to the mechanical engineer that he can now avail himself, for the practical transmission of power, of that silent carrier electricity—a carrier which, while it can communicate a great force almost instantaneously to a vast distance through a thin wire, travels itself so leisurely that, in its steady flow, it experiences no extra difficulty whether it goes up hill or down dale, overhead or underground, in a straight line or round a succession of sharp corners.

EXPERIMENTS IN AËRODYNAMICS.[2]

THE subject of this memoir is of especial interest at the present time, when the skill of a distinguished inventor is understood to be engaged in attacking the many practical difficulties which lie in the way of artificial flight upon a large scale. For a long time the resistance of fluids formed an unsatisfactory chapter in our treatises on hydrodynamics. According to the early suggestions of Newton, the resistances are (1) proportional to the surfaces of the solid bodies acted upon, to the densities of the fluids, and to the squares of the velocities; while (2) "the direct impulse of a fluid on a plane surface is to its absolute oblique impulse on the same surface as the square of the radius to the square of the sine of the angle of incidence." The author of the work[3] from which these words are quoted, in comparing the above statements with the experimental results available in his time (1822), remarks:—"(1) It is very consonant to experiment that the resistances are proportional to the squares of the velocities. . . . (2) It appears from a comparison of all the experiments, that the impulses and resistances are very nearly in the proportion of the surfaces. . . . (3) The resistances do by no means vary in the duplicate ratio of the sines of the angle of incidence." And he subsequently states that for small angles the resistances are more nearly proportional to the sines of incidence than to their squares.

It is probable that the law of velocity tended to support in men's minds the law of the square of the sine. For, if both be admitted, it follows that the resistance, normal to the surface, experienced by a plane when immersed in a stream of fluid, depends only upon the *component* of the velocity perpendicular to the surface. That the effect should be independent of the component parallel to the plane seems plausible, inasmuch as this component, *if it existed alone*, would exercise no pressure; but that such a view is entirely erroneous has been long recognized by practical men, especially by those concerned in navigation.

From the law of the simple sine, enunciated by Robison, it follows at once that the pressure upon a lamina exposed perpendicularly to a stream may be increased *to any extent* by imparting to the lamina a sufficiently high velocity *in its own plane*. The immense importance of this principle was clearly recognized by Mr. Wenham in his valuable paper upon flight;[1] and a few years later the whole subject was discussed by the greatest authority upon such matters, the late Mr. W. Froude, with characteristic insight and lucidity.[2]

The theoretical problem of determining the resistance from the first principles of hydrodynamics is not free from difficulty, even in the case of two dimensions, where a long rectangular lamina is exposed obliquely to a stream whose direction is perpendicular to the longer sides. The formula[3] resulting from the theory of Kirchhoff, viz.

$$\frac{\pi \sin \alpha}{4 + \pi \sin \alpha} \rho V^2, \quad . \; . \; . \; . \; . \; . \; . \; (1)$$

where ρ is the density of the fluid, and V is the total velocity of the stream flowing at the angle α with the plane of the lamina, shows that when α is small the resistance is nearly proportional to sin α. Moreover, (1) agrees with the experiments of Vince.[4]

It will be seen that the laws of resistance were fairly well established many years ago, at least in their main outlines. Nevertheless, there was ample room for the systematic and highly elaborate experiments recorded in the memoir whose title stands at the head of this article.

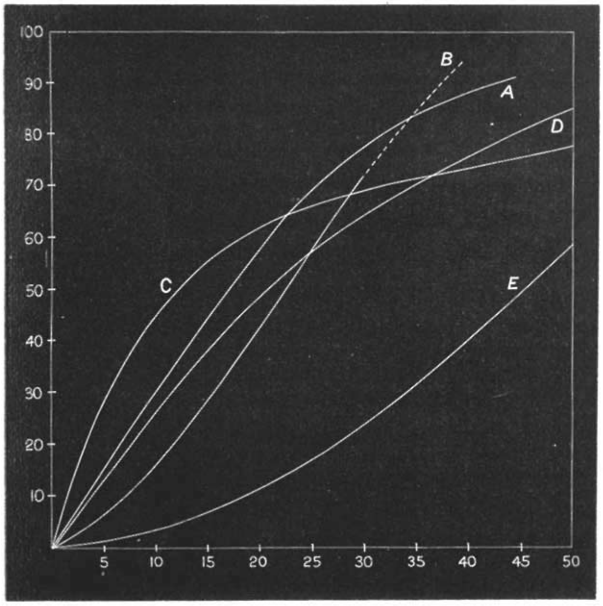

FIG. 1.

The work appears to have been executed with the skill and thoroughness which would naturally be expected of the author, and will doubtless prove of great service to those engaged upon these matters. The scanty reference to previous knowledge, which Prof. Langley holds out some promise of extending in subsequent publications, makes it rather difficult to pick out the points of greatest novelty. The main problem is, of course, the law of obliquity, and this is attacked with two distinct forms of apparatus. The general character of the results, exhibited graphically on p. 62, will be made apparent from the accompanying reproduction, in which are added a curve D,

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[1] We are indebted to *Industries* and the *Electrician* for some of the illustrations used in this article.

[2] "Experiments in Aërodynamics." By S. P. Langley. "Smithsonian Contributions to Knowledge." (Washington, 1891.)

[3] "System of Mechanical Philosophy," by John Robison, vol. ii., 1822.

[1] Report of Aëronautical Society for 1866.

[2] Proc. Inst. Civ. Eng., 1871 (discussion upon a paper by Sir F. Knowles).

[3] See *Phil. Mag.*, December 1876. Also Basset's "Hydrodynamics," vol. i. p 131.

[4] Phil. Trans., 1798.